Journal of Environmental Analytical Chemistry
ISSN: 2380-2391

Sturaro et al., J Environ Anal Chem 2016, 3:2
DOI: 10.4172/2380-2391.1000179

Research Article Open Access

# Analysis of Metals and Surface Modification of Leaves for the Evaluation of Forest Fires Started by Electrical Discharge

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## Abstract

Forest fires are generally consciously or unconsciously the work of man for various reasons. Fires generated by voltaic arc between power lines and the underlying trees do not occur often. These few cases may be only demonstrated by analyzing around the site where the arc may have been generated. Material such as leaves, bark and soil can be analyzed to find the metallic residues from the fused cables. The electrical cables usually composed of aluminum or copper alloys, when involved in an electric arc may spray fused micro-drops of metals, increasing the natural level of such elements. In two cases, the Al and Cu concentrations were increased by between 2.56 to 13.9 times the background levels. Electron microscopy of leaf surfaces has identified some profound alterations produced by the intense heat of the electrical discharge.

**Keywords:** Tree leaves; Power lines; Metal traces; ICP-OES

## Introduction

In Europe, more than 95% of forest fires have been attributed to human causes. Sources of human-caused fires include arson, accidental ignition, or the uncontrolled use of fire in land-clearing [1]. The rest are due to doubtful cases and a very small number to natural events. In Italy, during the year 2013, only 2% of cases were attributed to possible natural causes. In more than 200 forest fires studied over a decade, only two cases have been attributed to electrical causes [2-4]. Doubtful cases are sometimes attributed to natural events. Fires attributed to natural events are usually started by lightning, usually in the summer months in the later afternoon or early evening. Excluding fulgurite formation in soil, there are not many chemical indicators for such an attribution [5]. Fulgurites are formed when lightning with a temperature of at least 1,800°C melts silica on a conductive surface and fuses mineral grains together; the fulgurite tube is the cooled product [6]. Fulgurites can also be produced when the cables of a high voltage electrical distribution network break and the wires fall onto a sandy surface. To ensure the safety of power lines and the continuity of supply of the service, proprietary companies are required to keep the overhead power lines clear of vegetation, creating real corridors within the wooded areas. Maintenance of power lines must be carried out in compliance with standard IEC 50110 and D.M. 21/03/88 No. 449. The areas are subject to radical cutting of trees, shrubs and bushes. The cutting must open a vegetation free passage within the power line easement buffer, about 30 meters wide, 15 meters on each side of the axis line. The area, obtained as above, require frequent and expensive interventions. Depending on the type of vegetation, it is normally provided for at least two-year maintenance. In fact, the vegetation tends to quickly re-colonize the area to find light and space.

The long-distance transport of energy is more efficient by operating at high voltage with a three-phase system. Compared to a single-phase alternating current system, of equal power, the cost of the material and the electrical cables is halved. The wires that transport electricity across the network to consumers, in unusually high winds, or in combination with other extreme or unusual conditions such as very high temperatures, can sway abnormally leading them to touch or come in such close proximity to each other that electricity is able to arc between the conductors. These events can lead to fires and other hazards. The electrical discharge leads to fusion of metal cables [7,8] and to the dispersion of metal spray around the site. Micro-drops of the fused metal may drop onto the leaves and bark of the trees. When trees are close to power lines, they can be electrocuted and can carry the electric current down through their trunks to the soil and sometimes start fires in the undergrowth. The chances of a tree becoming electrocuted are drastically increased when it is under power lines or dangerously near them.

This phenomenon is not easy to identify because the power lines may have been damaged during the fire making it sometimes impossible to identify the vegetation or the power line as the origin of the fire. Whether it is arson or an accidental interaction between the electrical cables and vegetation, the economic and social damage can be elevated and therefore identifying unambiguously this cause is extremely important.

Atomic absorption spectroscopy was used to identify copper, zinc, lead and iron deriving from an electric discharge on pig skin [9]. Investigations of the surface by X-ray photoelectron spectroscopy (XPS) may also contribute to identifying electrical arcs as primary or secondary causes of fire [10]. The morphological and chemical characteristics of deposited individual particles have been investigated using scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDAX). The concentrations of trace metals (Pb, Cu, Zn, Cd) in the water-soluble fraction of deposits on single leaves were measured with differential pulse anodic stripping voltammetry (DPASV) [11]. The aim of this work was to set up a reliable and methodological approach to sampling and analytical procedures to investigate the metals deposited on tree leaves and bark to identify their sources.

This paper reports the results obtained by ICP-OES analysis of copper and aluminum metal and some SEM-EDS observations obtained from analyzing the leaves and bark from two fires where an electrical arc was considered the cause.

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**Received** March 22, 2016; **Accepted** April 30, 2016; **Published** May 06, 2016

**Citation:** Sturaro A, Vianello A, Guerriero P, Rella R (2016) Analysis of Metals and Surface Modification of Leaves for the Evaluation of Forest Fires Started by Electrical Discharge. J Environ Anal Chem 3: 179. doi:10.4172/2380-2391.1000179

## Materials and Methods

### Samples

The laboratory received two sets of samples from the State Forestry Corps that consisted of leaves and branches from two sites where fires in the undergrowth had started (32 T 493386.04 mE, 4946128.02 mN and 32 T 531921.57 mE, 5080229.06 mN). The causes were unsure, arson was ruled out and there was evidence of an electric discharge due to the presence of power lines. In the first fire case, the upper branches of a locust-tree (*Robinia pseudoacacia)* had grown as high as the high voltage cables probably causing an electrical arc between them. The *Robinia pseudoacacia L.* is a plant of the Fabaceae family from North American now naturalized on the all European continent. The major concentration of Italian locust forests occupies the sub-mountain range with very steep slopes and bumpy. The locust has the particularity to enrich the soil of nitrogen and hold it thanks to the radicals suckers issued after each cut. The locust plants have the characteristic of increasing very quickly in height but little in diameter of the stem. These features make these woods particularly difficult for the management of the vegetation in the proximity of the power lines. The leaves of the second sample appeared completely dried with green-brown colored inhomogeneous upper surface. The samples from the second site were from an aspen tree, (*Populus tremula*) that had grown too close to the area under the power line, and had fallen onto the electrical cables. The samples were from the apical leaves and the bark that had been directly affected by the electric discharge. As an electrical discharge was almost certainly responsible for this fire, these second sets of samples were used as reference samples and positive controls. All samples were taken with the necessary precautions and stored in paper bags to prevent external contamination and mold growth (Figures 1-4).

### Analytical methods

Two aliquots of each sample (500 mg) were extracted by stirring overnight with 15 ml of 5% *v/v* $HNO_3$ in aqueous solution. Each acid extract was filtered analyzed using an ICP-OES (Varian Liberty series II) for determination of the target metals. Copper and aluminum were determined using a suction flow of 1.5 ml/min, the wavelengths corresponding to the maximum emission, 324.754 nm and 396.152 nm respectively and applying the polynomial background correction method. The analysis of each extract was repeated 3 times. The raw data, represented by the average of the six measurements for each sample, were transformed into concentration against an appropriate calibration and are expressed as cg/g of each metal in the sample. Additional reference samples of leaves and bark from the same kind of tree, far from the fire sites and under the same power line, have been sampled and treated as before to verify the base level of each target metals [12-14].

The surface morphology of the leaves and the presence of micro-drops of metal were studied by scanning electron microscopy energy dispersive spectroscopy (SEM-EDS). The analyses were performed on a Philips XL40 scanning electron microscope equipped with a LaB6 source. The system was coupled with an EDAX microanalysis probe able to detect atomic elements with masses higher then sodium. Using these detectors, the morphology and elemental composition of some material found on the surface of the samples were obtained. These samples were analyzed without any pretreatment, ensuring the possibility of performing the same or other analyses in future. The microscopic images obtained from each sample were compared with those obtained from reference samples after a heat treatment in an oven at a temperature between 110 and 120°C for 30 minutes.

## Results and Discussion

The amount of aluminum residue, deriving from the fusion of high voltage electrical cables, was found to be from braided aluminum alloy (Aldrey: 99% aluminum, 0.5% magnesium 0.5% silica) as determined by ICP-OES, the results are reported in the Table 1. The samples nearer the apex of the plant (*R. pseudoacacia* 4, 5) showed significant increases compared to the levels found on leaves from a reference tree and branches on the same tree away from the top. In the second case, the electric arc was caused by the tree falling directly onto the copper wire. Samples of leaves did not show significant increases in copper, however, analysis of the portion of the bark coming in contact with the cables showed a value of 52.9 +/- 0.31 µg/g an increase of 13.9 times over the reference bark. A value of 3.8 +/- 0.83 µg/g was found for an area of the same tree not affected by the arc.

The SEM-EDS analyses on both sides of the leaves showed some fine particles singly or gathered in agglomerates of various shapes. The particles were mostly present on the adaxial leaf surfaces. The chemical composition was investigated by SEM-EDS, the most abundant particles were ashes and dust (Si, Al, Fe, Mg, N, S, P, Ca, K). Metal-rich particles were not observed.

It is suggested that the particles deposited on the leaves are mostly from the underbrush fire. It is very difficult to draw a common conclusion about the relative amount of water-soluble metals and the EDS analyses of trace metals on the plant material. However, morphological analysis of the leaf surfaces showed some significant details that were definitely caused by the electric arc. On the adaxial surface of the leaves from both sample sets, there were fractures and craters not present on the reference leaves.

| Leaf sample | Al (µg/g) | SD | Increase factor |
|---|---|---|---|
| *R. pseudoacacia* reference | 5.96 | +/- 1.53 | 0 |
| *R. pseudoacacia* 1 | 6.18 | +/- 0.21 | 1.03 |
| *R. pseudoacacia* 2 | 11.05 | +/- 0.35 | 1.85 |
| *R. pseudoacacia* 3 | 11.7 | +/- 0.32 | 1.96 |
| *R. pseudoacacia* 4 | 12.95 | +/- 0.82 | 2.17 |
| *R. pseudoacacia* 5 | 15.24 | +/- 0.27 | 2.56 |

**Table 1:** Aluminum amounts in the leaf samples expressed as micrograms of metal per gram of dried leaves. The last column shows the factor of increase for each sample compared to the unexposed reference sample.

**Figure 1:** The two sites where undergrowth fires had started. In the first case (on the left) the branches were not in direct contact with the electrical cables.

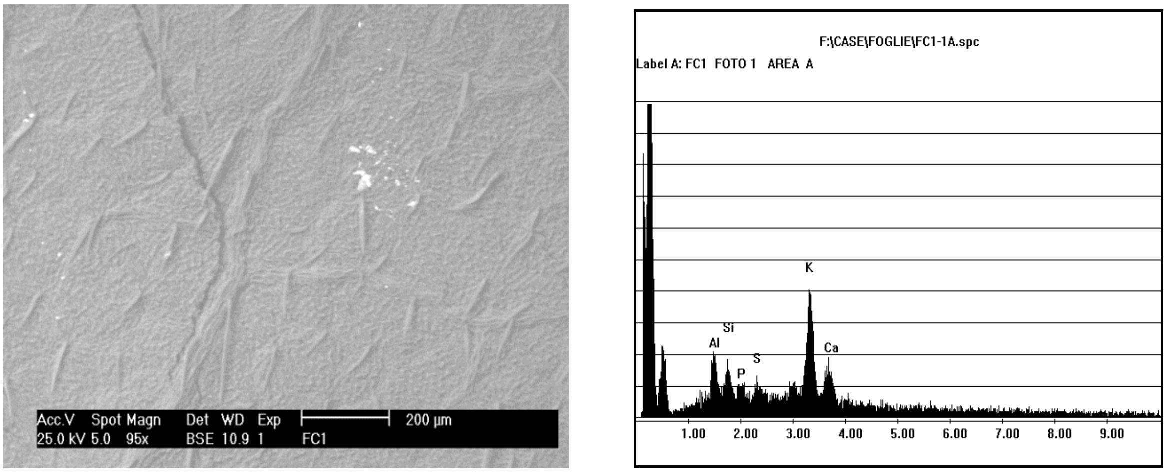


**Figure 2:** Scanning electron micrograph of the adaxial leaf surface from the *"locust-tree 5"* sample (left); EDX-spectrum of a particle on the left (right).

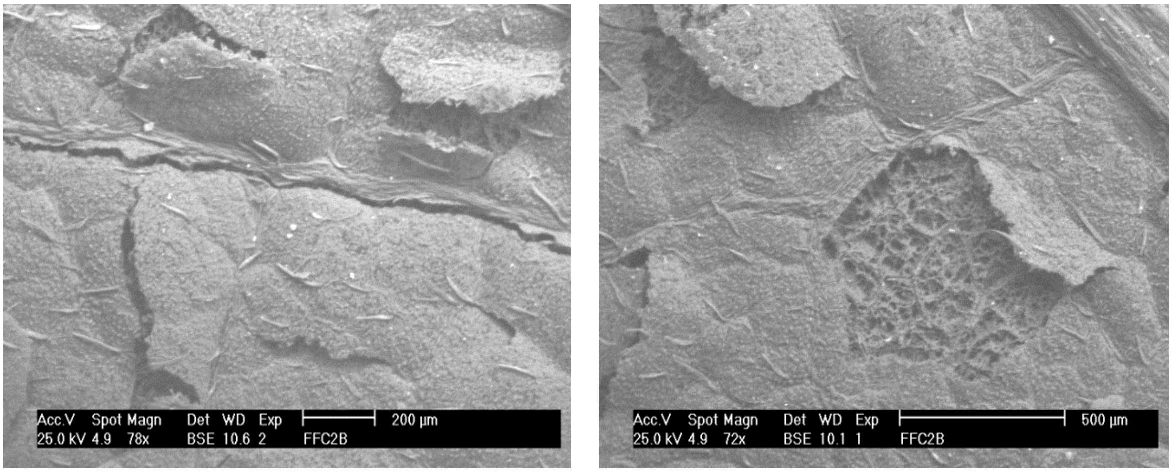


**Figure 3:** Scanning electron micrograph of the adaxial leaf surface from the *"locust-tree 5"* sample.

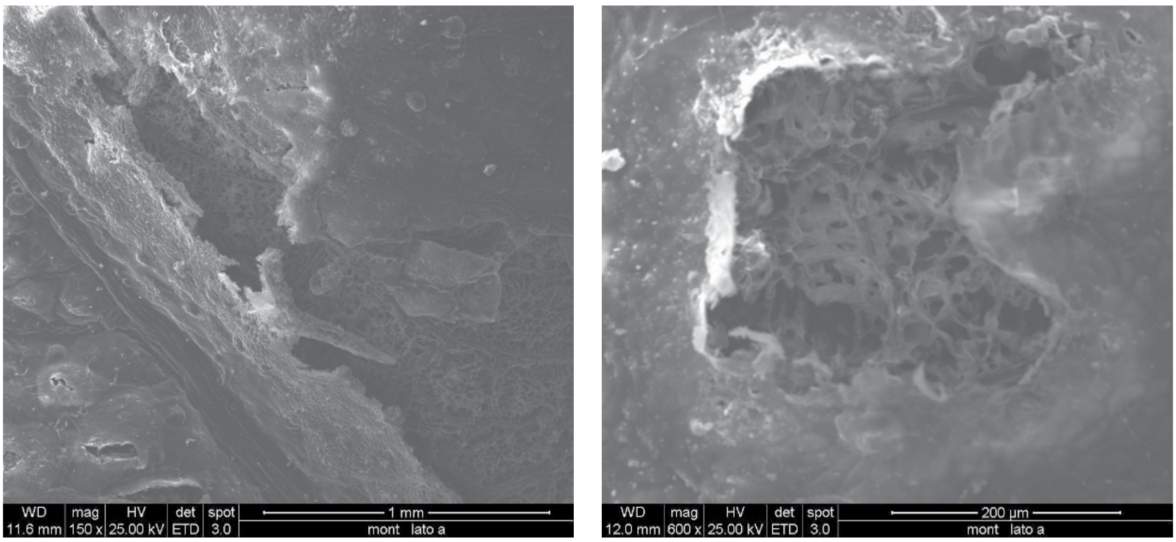


**Figure 4:** Scanning electron micrograph of the adaxial leaf surface from the *"Populus tremula"* sample.

An electric arc can reach very high temperatures in a split second. The sap inside the leaves and branches is a poor conductor, its electrical resistance causes a rapid heating and explosion into steam, which blows out the leaf cuticle and the bark of the tree.

## Conclusion

Electric arcs, particularly in the case of high-voltage power lines, can produce fusion of the cable with the consequent fall of molten material onto the vegetation, which, in conditions of prolonged drought can cause fires. In addition, the electrical discharge is able to propagate from the branches to the trunk reaching the ground where it can start a fire in the dry material. These phenomena are macroscopic and sometimes have a destructive outcome that can make it hard to obtain evidence. However, these phenomena are accompanied by microscopic phenomena detectable by chemical and microscopic investigations whose interpretation can demonstrate the nature of the event. The production of microspheres of fused metal, although not shown in electron microscopy is confirmed by analysis by ICP-OES of the leaves involved. The high water content, typical of the vegetative stage, is able to absorb the heat produced by the electric discharge and produce steam without any combustion phenomena. The rapidity of the phenomenon produces a high pressure in the mesophyll tissue responsible of fractures and craters visible on the leaf surface when analyzed by electron microscopy. The electrical discharge produced by the high voltage power lines when it reaches the ground can produced high heat that may cause the burning of dry plant material that is not able to absorb and dissipate the heat through the evaporation of water as occurs on the leaves and twigs. The very low number of fires due to electric arc and the great difficulty to set empirical laboratory experiments do not enable a statistical evaluation of the data.

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